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ELECTRODES FOR FUNCTIONAL NEUROMUSCULAR STIMULATION

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Section A: Clinical Collaboration

The goal of this work is to collaborate with local clinical centers to identify areas of need and to develop specifications for electrodes for motor prostheses. During the first quarter we have met with both our lower extremity and upper extremity clinical collaborators.

Lower Extremity (Marsolaïs, Scheiner, Osmond)

Two applications have been identified for immediate need in the area of electrode development: activation of the hamstrings branch(es) of the sciatic nerve and activation of the iliopsoas (hip flexor). Our clinical collaborators have dissected one cadaver specimen and found the following results.

There were two branches of the sciatic nerve that innervated the hamstrings group. The first branch occurred 10 cm distal to the inter-trochanteric (I-T) line and innervated the long head of biceps femoris and the upper half of the semitendinosus. The second branch occurred 15-17 cm distal to the I-T line and innervated the lower half of semitendinosus, semimembranosus, and the erector magnus (posterior abductor). Each branch had a readily accessible length of approximately 3 cm and was 3-5 mm in diameter. It seems likely that, for this application, two electrodes (one on each branch) would be connected to a single stimulator channel. The desired current balance between the two electrodes could be achieved by placing a resistance in series with each electrode to achieve the desired current divider.

During the next quarter another cadaver specimen will be dissected and accurate measurements of nerve branch diameters will be made using the circumferential nerve gauge previously developed in our laboratory. We will supply our collaborators with several practice electrodes and work with them to design the first generation of endoscopic implant tools.

Upper Extremity (Peckham)

We have had two meetings with our upper extremity collaborator to review our previous work with cuff electrodes and to outline the goals during the present contract. The goal for the next quarter is to work with Dr. Peckham to develop specifications for a minimum system using multiple contact spiral cuff electrodes to restore hand grasp.

Section B.1: Design and Fabrication of a Jig to Wind Helical, Multiple Lead Cables

The goal of this sub-project is to develop methods to wind multiple-conductor helical lead cables. These cables are required to make reliable long-term connections to multiple contact nerve cuff electrodes.

There was a need to modify our existing winding machine to wind multiple wires in an even and reproducible manner. The existing system uses a tension motor to feed the bulk wire onto the spinning mandril and form the helical cable. Problems arose when multiple wires (three or more) were being wound together. The motor would maintain the specified total tension, but the tensions on the individual wires varied. This produced poor quality lead cables that were loose and uneven.

The solution to this problem was to maintain the tension individually in each wire. In the modified system, the tension in each wire is maintained by individual hanging weights (see Figure 1). These weights, under the force of gravity, keep a constant tension in each wire. To accomplish this, a junction between the wire and the weight system, a weight rack, and a mechanism to convert the downward force due to gravity into a horizontal tension were required.

To convert the force of gravity acting on the weights into a horizontal tension and to keep the wires separated as they were fed onto the winder, a very stiff steel spring with 8 coils was mounted on the carriage (Figure 1). The individual lead wires are attached to the mandril and then fed through the spring where each wire bends around one coil of the spring (allowing up to 8 wires at a time). The wire then runs upward and connects to a string which lies over the ceiling bar and is secured to the weight rack. Presently, the connection between the wire and the string is made by using an alligator clip tied to the end of the string.

The strings travel up and over the ceiling bar (1.5 m x 1.3 cm) which is supported 7.6 cm below the ceiling at the proximal end and 15.2 cm from the ceiling at the distal end. This forms a slight slope along the ceiling bar that aids the movement of the strings along it as the helix is formed. It was found that the sliding of the strings as they get pulled over the bar was smoother than any of the passive shuttle systems tried. The distance from the ceiling bar to the spring (i.e., the usable distance of straight electrode wire) is approximately 1.2 meters. This will allow winding of lead cables 0.6 m in length.

The weight rack is simply a hook passing through a hole drilled in a large, inverted bolt. Weights (washers) can be added and removed from the bolt to modify the tension in the lead wires. The tension can be adjusted in 5 gram increments with the present weights.

We have used this system to wind successfully helical lead cables consisting of four individual lead wires. Each lead wire is Teflon insulated seven stranded stainless steel, as used for our intramuscular electrodes. Problems with the present system

include twisting of the strings and connection of the wire to the string. The problem of the strings twisting is caused by the strings being pulled over the bar and the string twisting according to the individual threads. By exchanging one of the strings for monofilament nylon, we found that most of this twisting was eliminated. This change also allowed smoother movement along the ceiling bar. The rest of the strings will thus be replaced with monofilament nylon. The problem with the connection between the string and the wire is slightly more difficult. When trying to wind small, single stranded wires (i.e., 40 μm outer diameter), the alligator clip cannot hold the wire against the force of gravity acting on the weights. During the next quarter we will investigate other techniques and connectors to wind small caliber wires using the modified winder. We will also investigate adding a second spring on the opposite side of the winder such that there is an even tension on the winder from both sides. This will minimize lateral displacement of the spinning mandrel and will double the number of wires that can be wound in a single cable.

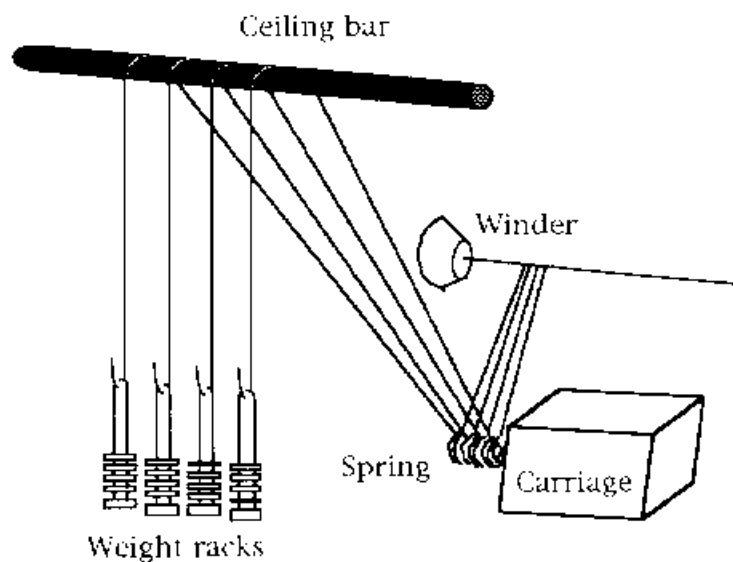


Figure 1: Schematic of apparatus to wind multiple conductor lead cables.

Section B.2: Techniques to Attach Lead Wires to Thin-Film Bonding Pads

The goal of this sub-project is to investigate conductive epoxy as a means to attach lead wires to thin-film metallic bonding pads. Our first objective is to determine the effect of a saline soak at elevated temperature on the adhesive properties of conductive epoxy. During this quarter we have designed a series of experiments to accomplish this objective.

The experimental system we have chosen consists of two stainless steel rods (0.32 cm diameter) joined together at one end by conductive epoxy (Figure 2). This simple system was chosen so that the properties of the conductive epoxy could be studied, rather than the properties of a complex joint geometry (e.g. between a lead wire and a bonding pad). We also wanted a system that allowed reproducible fabrication of test specimens.

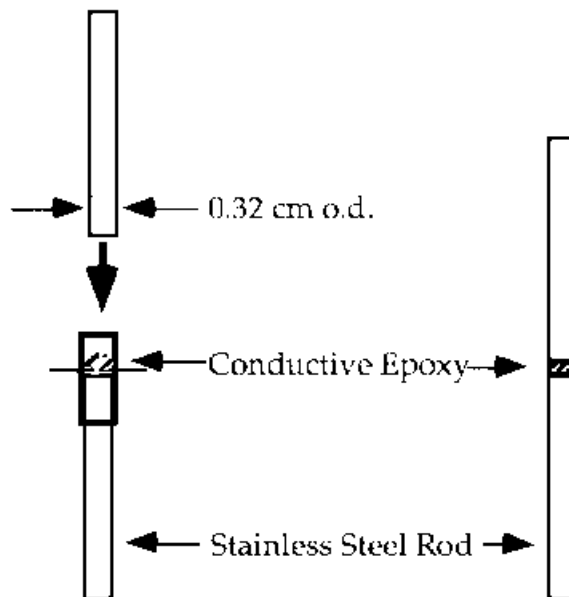


Figure 2: Specimens to test properties of conductive epoxy.

During this quarter, we have designed and constructed a jig to fabricate the test specimens (Figure 3). One of the stainless steel rods is mounted in each of the two plates. A Teflon sleeve containing a 25 μm diameter spacer will be placed over the lower rod to ensure uniform inter-rod spacing in the different test specimens. A measured amount of conductive epoxy will be placed on the surface of the lower rod, and the two rods will be brought together under the force of gravity acting on the upper plate. The Teflon sleeve ensures that no epoxy will leak out between the rod ends, which could introduce variability between samples. The epoxy will then be cured in an oven.

After curing we will examine the mechanical and electrical properties of the junction. The resistance of the junction will be measured and monitored while the test specimen is broken in an Instron test apparatus. A stress-strain curve will be recorded during the breaking process to quantify the yielding and fracture properties of the junction. After fracturing, the junctions will be examined using light and electron microscopy to determine the failure mode at the junction (i.e., did the epoxy fracture or did the bond between the epoxy and the stainless steel rod end rupture).

During the next quarter we will study two groups of specimens, with ten samples in each group. The first group will be fabricated as described above and then left in air at room temperature for five days before testing. The second group will be fabricated as described above, but will be soaked in saline at 60° C for five days before testing. This will allow us to determine the reliability of the conductive epoxy.

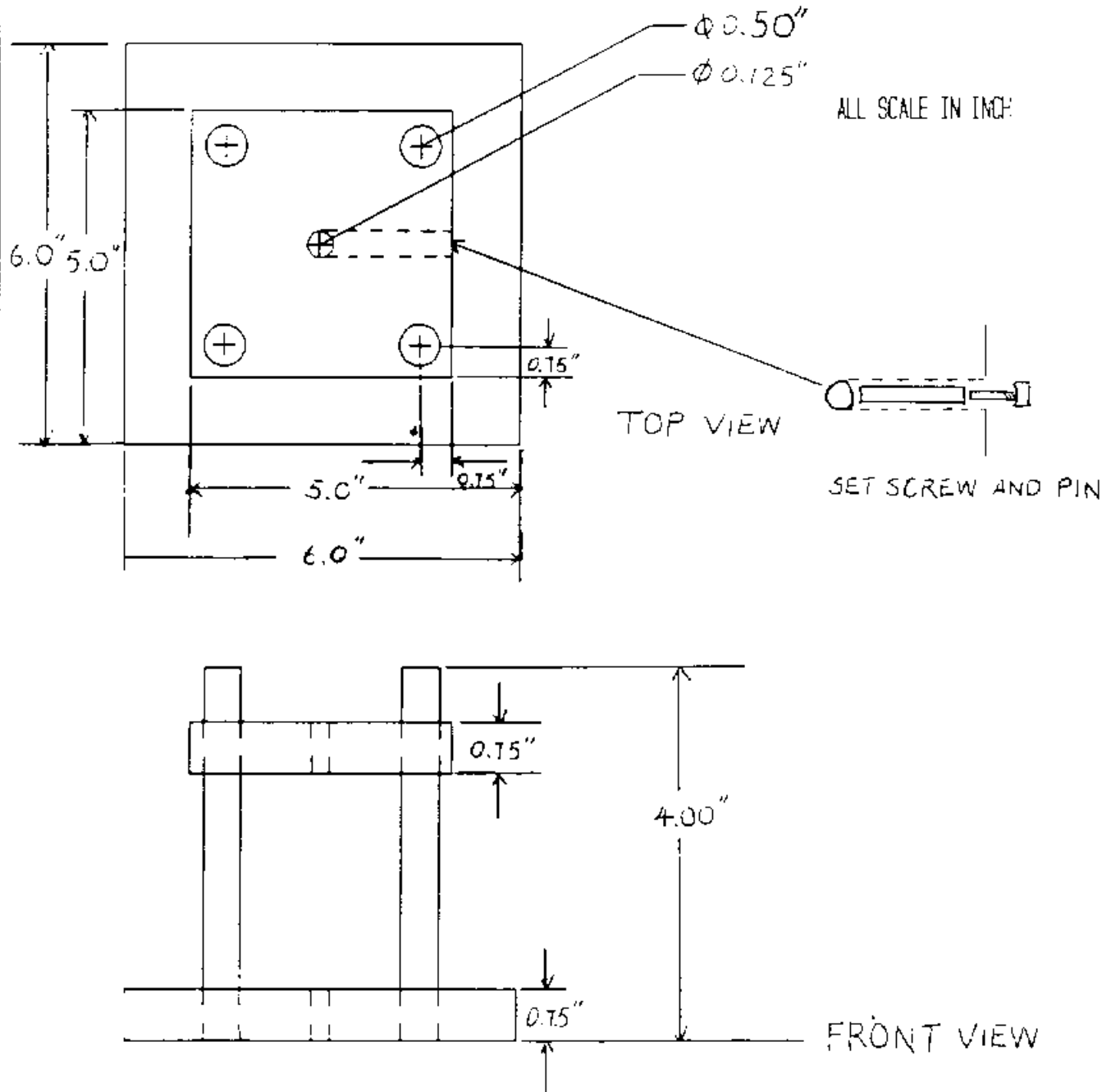


Figure 3: Schematic of jig to fabricate test specimens.